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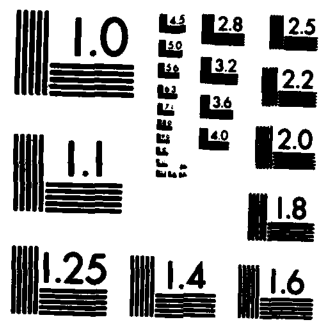

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Polytechnic Institute of New York

MICROWAVE RESEACH INSTITUTE

POLY-MRI-1424-82
December 1982

QUASI-OPTIC STUDIES OF DIELECTRIC RADOMES AND LENSES

FINAL REPORT

L.B. Felsen and A. Hessel

December 14, 1982

U.S. ARMY RESEARCH OFFICE
GRANT NO. DAAG-29-78-G-0168

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A124 371	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) "Quasi-Optic Studies of Dielectric Radomes and Lenses"		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER POLY-MRI-1424-82
7. AUTHOR(s) L. B. Felsen and A. Hessel		8. CONTRACT OR GRANT NUMBER(s) DAAG-29-78-G-0168
9. PERFORMING ORGANIZATION NAME AND ADDRESS Polytechnic Insitute of New York Microwave Research Institute Route 110, Farmingdale, New York 11735		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE December 14, 1982
		13. NUMBER OF PAGES 9
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

N/A

18. SUPPLEMENTARY NOTES

The view, opinions, and/or findings contained in this report are those of the author(s) and should not be contrued as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Quasi-optics, transmission through radomes, ray tracing.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This grant has been concerned with work on the transmission and guiding characteristics of dielectric radomes and lenses. Emphasis has been placed on novel techniques that promise: a) to facilitate the near-to-far field transition calculations for highly collimated distributed aperture fields, and b) to facilitate and systematize ray-optical treatment of multiple reflections inside the radome, of curvature effects, of wave trapping, and guiding, etc. In case a), the investigation centered on complex ray methods. In case b), it lead to a new and rigorous procedure for treating the prototype

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cylindrical shell Green's function in terms of ordinary and composite ray fields, with the latter accounting collectively for multiple internally reflected rays. The accomplishments suggest that these procedures offer a promising new approach to the radome problem.

ABSTRACT

This grant has been concerned with work on the transmission and guiding characteristics of dielectric radomes and lenses. Emphasis has been placed on novel techniques that promise: a) to facilitate the near-to-far field transition calculations for highly collimated distributed aperture fields, and b) to facilitate and systematize ray-optical treatment of multiple reflections inside the radome, of curvature effects, of wave trapping and guiding, etc. In case a), the investigation centered on complex ray methods. In case b), it lead to a new and rigorous procedure for treating the prototype cylindrical shell Green's function in terms of ordinary and composite ray fields, with the latter accounting collectively for multiple internally reflected rays. The accomplishments suggest that these procedures offer a promising new approach to the radome problem.

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I. Background

A comprehensive study of the influence of radomes and lenses on the field radiated by a prescribed aperture distribution was initiated under this contract. Emphasis was placed initially on the investigation of new methods of analysis, which appeared to have the potential of making the field evaluation per se more accurate and the near-to-far-field transition calculations more efficient. In connection with the former objective, an essential building block toward effective analysis of general radomes seemed to be a ray-optical scheme whereby one could treat in an efficient manner the multiple internal reflections and could also account, when necessary, for guiding effects associated with the dielectric shell. As to the latter objective, evanescent wave and complex ray methods for beam type aperture distributions looked promising since such techniques permit, in principle, the tracking of fields from the near zone to the far zone without need of integration over an equivalent aperture in the near zone.

To deal with these objectives, a thorough investigation of carefully chosen fundamental protype problems was undertaken in order to develop the proposed new methods and test their viability. This effort has been successful and has led to a detailed understanding of the wave processes relevant to the radome problem. As a consequence, the foundation has been laid for a new approach to the analysis of radome and lens configurations.

II. Accomplishments

A. Evanescent Waves and Complex Rays

A thorough study of the mechanism of propagation of evanescent waves was undertaken with a view toward establishing the feasibility of tracking the field from a beam-type aperture distribution through a radome to the far zone without performing an auxiliary (and often costly) integration over an equivalent aperture surface. Such integration has been customary for large aperture reflecting and transmitting systems, with the equivalent-aperture field established by ordinary ray or by physical optics methods. Ordinary ray methods, as expressed by the geometrical theory of diffraction (GTD), are based on tracking local plane wave fields with real phase; they fail to predict the far field due to a focused-beam aperture distribution and therefore necessitate the above-mentioned integration.

Evanescent wave tracking (EWT), based on local plane wave fields with complex phase, avoids the difficulties encountered by GTD. The tracking is performed along "phase paths", which describe smoothly the transition from the focused field in the near zone to the radiation field at great distances. A principal difficulty with EWT is the determination of the phase paths, which depend strongly on the initially prescribed field values. Their behavior is governed by trajectory equations that are considerably more complicated than the ray equations of GTD. Since the phase paths track the envelope of the exponentially tapered field, their accurate determination is of prime importance.

Our study has led to a set of procedures that are numerically tractable and sufficiently accurate for calculation of the phase paths and the corresponding fields. Our first attempt has been to seek initially an exact solution of the phase path equations, if possible, for a special, but non-trivial, set of initial conditions. A set of confocal hyperbolic phase paths, with corresponding (orthogonal) elliptical phase fronts, furnishes such a solution.

It had been hoped that the hyperbolic paths, which correspond to a particular "canonical" tapered aperture distribution, could be matched locally to aperture fields that depart from the canonical form, at least

in the (paraxial) weakly evanescent region near the maximum of beam-type fields. However, by comparison with independently calculated fields for various non-canonical aperture profiles, we have found that this is not generally applicable, although the procedure is adequate and advantageous for certain types of initial distributions. The deviation of the true phase paths from a hyperbolic shape can generally not be ignored for accurate calculation of the field.

The above-noted difficulties have been overcome by calculating the phase paths and fields via complex ray theory, which also describes the propagation properties of local plane wave fields with complex phase. Complex rays follow straight trajectories in a complex coordinate space. They originate on a complex initial surface with complex initial conditions generated by analytic continuation of the specified real initial data. An observable field is associated with the real-space intersection of a complex ray; the true phase paths of EWT correspond to those real-space intersections of complex ray fields satisfying the constraint of constant exponential amplitude. While ray tracing in a complex coordinate space is generally quite involved, the procedure does become tractable for "slightly complex" rays characterizing the weakly evanescent fields near the beam maximum. However, the complex ray fields per se, unlike the real-space fields of EWT, do not have a simple physical interpretation. It has therefore been concluded that complex ray theory should be regarded essentially as an algorithm for solving the EWT trajectory and field equations. This combined complex-ray and EWT approach is tractable, both analytically and numerically, and furthermore describes the complete evolution of the field from the near zone to the far zone in terms of physically significant wave processes.

The basic EWT and complex ray studies outlined above have been presented in a recent paper.[1] To further test the validity of the conclusions from this investigation, the EWT-complex ray approach has been applied to the direct tracking of an initial beam-type field from the source plane to the far zone via an intervening reflection at a paraboloidal surface. Here, the complex ray tracing required extension of the initial conditions as well as the reflector geometry into a complex coordinate space. The success of the procedure for the single reflector problem, as documented

in another paper[2] suggests that the more complicated problem of transmission through a dielectric radome may also be attacked in this manner. To this end, one requires a thorough knowledge of the asymptotic behavior of the radome Green's function, which forms an essential building block for synthesis of a distributed aperture field due to discrete or continuous source arrangements.

B. Green's Function for a Circular Cylindrical Radome

To explore an efficient representation of the radome Green's function that accounts for multiple internal reflections of impinging ray fields, and also for effects of surface curvature as well as for possible excitation of trapped and leaky modes guided along the radome, a rigorously analyzable prototype -- a line-source excited circular cylindrical dielectric shell -- was selected for detailed study. Starting from an exact integral formulation in an infinitely extended azimuthal coordinate space, alternative representations of the transmitted field were derived by contour deformations in the complex wavenumber plane, and by subsequent asymptotic treatment of the integrands. One of these representations has led to a series of ray integrals which contribute fields with multiple internal reflections between the radome walls, and also fields which arise, in addition, from multiple reflection on the concave inner boundary before transmission. A procedure has been found for systematic grouping of this hierarchy of ray contributions. Thereafter, it has been possible to account for the multiplicity of internal reflections in terms of a new "collective ray" field. The collective ray behaves like an ordinary transmitted ray, but with a composite transmission coefficient, similar to that for a plane parallel slab. However, the new transmission coefficient contains a curvature correction that has not previously been incorporated into models based on local approximations. There results then a novel hybrid formulation for the transmitted field comprising a number of conventional rays plus a collective ray whose form is related uniquely to the number retained of the former. Frequently, the collective ray alone may accurately express the entire transmitted field.

These conclusions are based on rigorous analysis and may also be reached by a direct ray-optical approach, with subsequent collective

treatment of rays with multiple internal reflections. Extensive numerical calculations demonstrate the effectiveness of the collective ray approach. Theory and numerical results are presented in a manuscript that has been submitted for publication.

III. Summary

The accomplishments listed in Section II have provided the basis for a new approach to the assessment of the effect of radome covers on the field radiated by localized as well as distributed source configurations. The prototype studies conducted so far should now be generalized to allow for more realistic configurations encountered in practice. Such extensions are presently being explored under Grant No. DAAG29-82-K-0097.

IV. Personnel

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PUBLICATIONS

1. P. D. Einziger and L. B. Felsen, "Evanescent Waves and Complex Rays," IEEE Transactions on Antennas and Propagation, AP-30 (1982), pp. 594-605.

2. F. J. V. Hasselmann and L. B. Felsen, "Asymptotic Analysis of Parabolic Reflector Antennas," IEEE Transactions on Antennas and Propagation, AP-30 (1982), pp. 677-685.

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